1.9 Newton's First Law of Motion

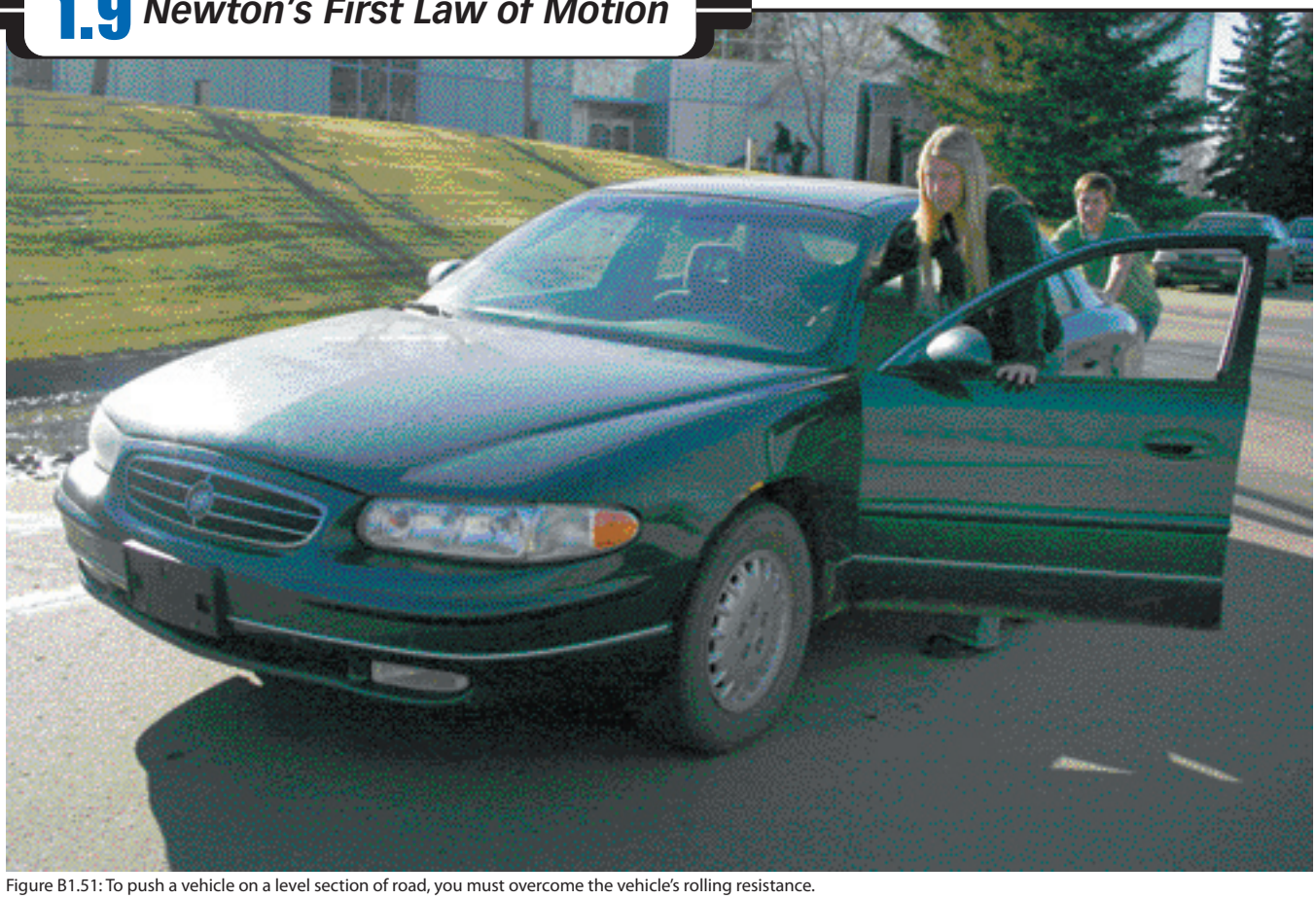


Figure B1.51: To push a vehicle on a level section of road, you must overcome the vehicle's rolling resistance.

So far, the analysis of forces on vehicles has been limited to the case of braking. In all of these cases, the force of friction between internal parts of the vehicle's braking system has primarily been the external, unbalanced force acting on the vehicle. In this context, frictional forces are desirable because they allow the vehicle to stop safely.

However, sometimes frictional forces are not desirable. If you have ever pushed a vehicle on a level section of road, you provided a force to overcome the rolling resistance of the vehicle. You needed to push fairly hard because it takes effort to overcome the friction within the vehicle's drive train to turn the wheels; and once the wheels start to turn, it takes effort to keep them turning because the tires flex and change shape as they roll. Normally, it's the engine that has to overcome the rolling resistance as the vehicle moves. At low speeds, the rolling resistance is the main force that opposes the motion of the vehicle.

Another undesirable frictional effect is air resistance. This can also be called "drag force" or "fluid friction." Think back to the last time you put your hand out of the window of a moving vehicle. If your palm faced forward, attempting to catch the air, the forces exerted on your hand would have been much larger than if you tried to slice through the air by leading with your fingertips. Vehicles encounter the same difficulties. In fact, at highway speeds, the force of air resistance is the main force that opposes the motion of a vehicle. Automotive designers try to find the most aerodynamic shapes possible so that air resistance can be minimized.

Figure B1.52: Air resistance is an undesirable frictional effect.

In circumstances in which the brakes are not engaged—a vehicle is speeding up or is travelling with a constant velocity—the rolling resistance and air resistance can be collectively referred to as the force of friction.

Newton's Second Law Applied to Speeding Up

applied force: an external force applied on an object

Newton's second law also explains what happens when a vehicle increases its velocity. This case is slightly more complicated because, now, there is another force to consider in addition to the force of friction. This additional force is generated by the vehicle's engine and through the tires' contact with the road as the vehicle moves forward. Since the application of this force is intended to make the vehicle move, it is usually called the **applied force**.

In the next activity you will demonstrate that the net force results from the vector sum of the applied force and the force of friction. You will also have an opportunity to investigate how the combination of these forces can be used to cause an object to speed up. This will be done, once again, using an applet.

Utilizing Technology

Factors Influencing the Rate of Acceleration

Purpose

Science Skills

✓ Analyzing and Interpreting

You will use the applet "Newton's Second Law," found on the Science 20 Textbook CD, to explore the relationships among the force of friction, the applied force, the net force, the mass of the vehicle, and the rate of deceleration. Since this activity does not deal with braking, the term force of friction refers to the combined effect of rolling resistance and air resistance that act to oppose the motion of the vehicle.

Background

Before starting this activity, you should familiarize yourself with the features of the applet by entering random values, clicking the Go button, and seeing what happens. Remember to click on the Reset button before you enter new values to begin a new trial.

Part A: Causing the Vehicle to Speed Up

Procedure

step 1: Copy the following data sheet into your notebook or into a spreadsheet.

Part A: Causing the Vehicle to Speed Up

Constant Values

Force of Friction = _____

Initial Velocity = _____

Mass = _____

Applied Force (N)	Net Force (N)	Acceleration (m/s^2)
+2000		
+3000		
+4000		
+5000		

step 2: Select the constant values in the applet: Force of Friction = -1000 N, Initial Velocity = +4.00 m/s, and Mass = 2000 kg. These values will be kept constant throughout this part of the investigation. Record these values in the appropriate places on the data sheet.

step 3: Set the initial value of the applied force to +2000 N.

step 4: Click the Go button, and observe the motion of the vehicle. Record the value of the net force and the acceleration in the appropriate places on the data sheet.

step 5: Repeat steps 3 and 4 for each of the following values of the applied force on the vehicle: +3000 N, +4000 N, and +5000 N. Record the values of the corresponding net force and acceleration for each applied force.

Analysis

1. Explain why the net force was 1000 N less than the applied force in each case.
2. Do your results support Newton's second law? Calculate the acceleration from the net force and the mass of the vehicle for your last trial to support your answer.

Check Your Understanding

3. A vehicle with a mass of 4000 kg is subjected to an applied force of +5000 N and a force of friction of – 3000 N.
   a. Determine the acceleration of the vehicle using the applet.
   b. Calculate the acceleration of the vehicle using the formulas.

Part B: A Special Case

Procedure

step 1: Copy the following data sheet into your notebook or into a spreadsheet.

Part B: A Special Case

Constant Values

Initial Velocity = _____

Mass = _____

Applied Force (N)	Force of Friction (N)	Net Force (N)	Acceleration (m/s^2)
+1000	-1000		
+2000	-2000		
+3000	-3000		
+4000	-4000		
+5000	-5000		

step 2: Select the constant values in the applet: Initial Velocity = +4.00 m/s and Mass = 1000 kg. These values will be kept constant throughout this part of the investigation. Record these values in the appropriate places on the data sheet.

step 3: Set the initial value of the applied force to +1000 N, and set the initial value of the force of friction to -1000 N.

step 4: Click the Go button, and observe the motion of the vehicle. Record the values of the net force and the acceleration in the appropriate places in the data sheet.

step 5: Repeat steps 3 and 4 for each of the other pairs of values for applied force and force of friction. In each case, record the values of the corresponding net force and acceleration.

Analysis

4. Use Newton's second law to explain why the acceleration values should be zero in each case.
5. Explain how the motion of the animated vehicle on the screen also indicated that the acceleration was zero.
6. Predict the effect on the vehicle's motion if the initial velocity was set to zero throughout each trial in Part B. Use the applet to verify your prediction.

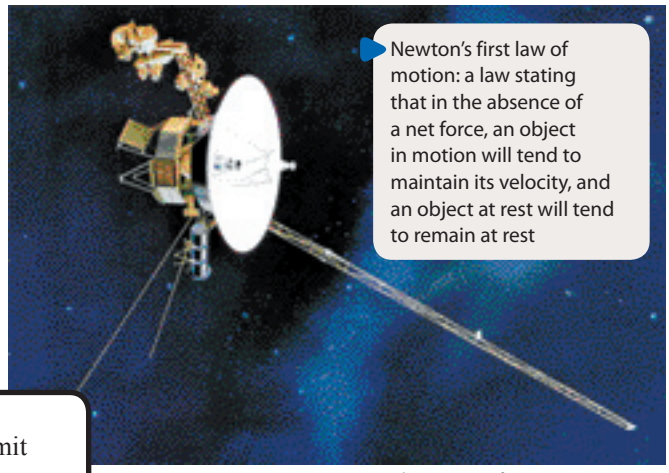
Check Your Understanding

7. A vehicle is given an initial velocity of 4.00 m/s when the force of friction is somehow made to be zero.
   a. Use the applet to determine the applied force that would be required to keep the vehicle moving uniformly at 4.00 m/s in these circumstances.
   b. Use Newton's second law to explain the value of applied force required to keep the vehicle moving uniformly at 4.00 m/s in these circumstances.

Newton's First Law of Motion

Part B of the previous activity demonstrated a curious result that is usually called **Newton's first law of motion**.

Newton's first law explains why a space probe with no crew, like *Voyager 2*, requires no engines to continue its journey beyond the solar system. In deep space, there are practically no forces slowing it down or speeding it up; so, the probe simply maintains its velocity.



Newton's first law of motion: a law stating that in the absence of a net force, an object in motion will tend to maintain its velocity, and an object at rest will tend to remain at rest

Figure B1.53: The success of Voyager 2 can be explained by Newton's first law of motion.

DID YOU KNOW?

Launched in 1977, *Voyager 2* will continue to transmit information back to Earth until 2020, when its nuclear generators will no longer be able to supply adequate electrical energy.

Example Problem 1.22

Determine the acceleration of each of the following vehicles. In each case, let the direction of the applied force be the positive direction.

a. The engine of a motorcycle supplies an applied force of 1880 N, west, to overcome frictional forces of 520 N, east. The motorcycle and rider have a combined mass of 245 kg.

b. A car with a mass of 1075 kg is travelling on a highway. The engine of the car supplies an applied force of 4800 N, west, to overcome frictional forces of 4800 N, east.

Solution

a. $m = 245 \text{ kg}$

$\vec{F}_a = 1880 \text{ N [W]}$
$= +1880 \text{ N}$

$\vec{F}_f = 520 \text{ N [E]}$
$= -520 \text{ N}$

$\vec{a} = ?$

First, determine the net force.

$$\begin{aligned}\vec{F}_{net} &= \vec{F}_a + \vec{F}_f \\ &= (+1880 \text{ N}) + (-520 \text{ N}) \\ &= +1360 \text{ N}\end{aligned}$$

Next, determine the acceleration.

$$\begin{aligned}\vec{F}_{net} &= m\vec{a} \\ \vec{a} &= \frac{\vec{F}_{net}}{m} \\ &= \frac{+1360 \text{ N}}{245 \text{ kg}} \\ &= +5.55 \text{ m/s}^2\end{aligned}$$

The acceleration is 5.55 m/s^2[W].

b. $\vec{F}_a = 4800 \text{ N [W]}$
$= +4800 \text{ N}$

$\vec{F}_f = 4800 \text{ N [E]}$
$= -4800 \text{ N}$

$m = 1075 \text{ kg}$

$\vec{F}_{net} = ?$

$\vec{a} = ?$

First, determine the net force.

$$\begin{aligned}\vec{F}_{net} &= \vec{F}_a + \vec{F}_f \\ &= (+4800 \text{ N}) + (-4800 \text{ N}) \\ &= 0\end{aligned}$$

Next, determine the acceleration.

$$\begin{aligned}\vec{F}_{net} &= m\vec{a} \\ \vec{a} &= \frac{\vec{F}_{net}}{m} \\ &= \frac{0}{1075 \text{ kg}} \\ &= 0\end{aligned}$$

The acceleration is zero.

Alternative Solution: According to Newton's first law, the car maintains its velocity and the acceleration is zero because there is no net force.

Newton's first law also has a lot to say about motion here on Earth. In the next two activities you will see how Newton's first law applies to automotive safety.

Utilizing Technology

Whiplash

Purpose

Science Skills
✓ Analyzing and Interpreting

You will use the applet "Newton's First Law: Whiplash," found on the Science 20 Textbook CD, to observe the effects of a rear-end collision on a crash test dummy in a vehicle with a head restraint and in a vehicle without a head restraint. You will use your observations to answer the question, "How does Newton's first law apply to the reduction of injuries through the use of head restraints in vehicles?"

Procedure and Analysis

Select Experiment mode to observe the motion of the balls. Remember, click the Reset button each time you try a different velocity value.

1. Use Newton's first law to explain the velocity of the ball after the crash if no head restraint is used. Select Real World mode to observe the motion of the crash test dummies. Pay close attention to the motion of the head relative to the body and the effect it has on the neck. Remember, click the Reset button each time you try a different velocity.
2. Use Newton's first law to explain the velocity of the crash test dummy's head after the crash if no head restraint is used.
3. Why are neck injuries so common in a rear-end collision where no head restraint is used?
4. How does Newton's first law apply to the reduction of injuries through the use of head restraints in vehicles?

Utilizing Technology

Forward Crash

Purpose

Science Skills
✓ Analyzing and Interpreting

You will use the applet "Newton's First Law: Forward Crash," found on the Science 20 Textbook CD, to observe the effects of a front-end collision on a crash test dummy in a vehicle with a seat belt and in a vehicle without a seat belt. You will use your observations to answer the question, "How does Newton's first law apply to the reduction of injuries through the use of seat belts in vehicles?"

Procedure and Analysis

Select Experiment mode to observe the motion of the balls. Remember, click the Reset button each time you try a different velocity value.

1. Use Newton's first law to explain the velocity of the ball after the crash if no seat belt is used. Select Real World mode to observe the motion of the crash test dummies. Pay close attention to the motion of the body relative to the vehicle. Remember, click the Reset button each time you try a different velocity.
2. Use Newton's first law to explain the velocity of the crash test dummy's body after the crash if no seatbelt is used.
3. Why are head injuries so common in a front-end collision if no seat belt is used?
4. How does Newton's first law apply to the reduction of injuries through the use of seat belts in vehicles?

Inertia

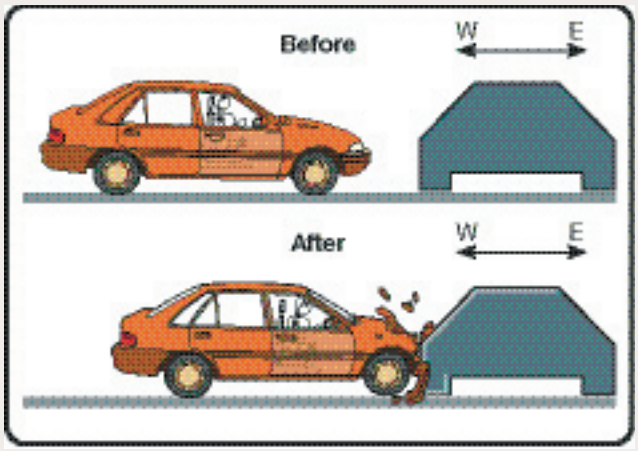
Another way to describe the behaviour of the objects you observed in the applets is to say that each object resisted changes in its motion due to a property known as its **inertia**. The amount of inertia an object has depends upon the mass of the object (measured in kilograms). This provides new insights into Newton's first law of motion because the greater the mass of an object, the more difficult it will be to change the motion of that object.

inertia: the property of an object to resist changes in its state of motion

Practice

47. In the game of football, there are circumstances in which a team is trying to advance the ball a few yards into the end zone to score a touchdown. One strategy that is frequently used is to hand the ball off to a player who is not only fast and agile, but who also has a large mass. Use the concept of inertia to explain the physics behind this strategy.

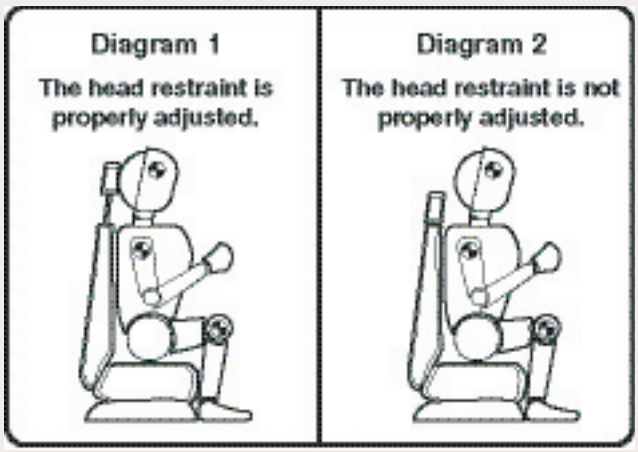
48. The following diagram shows a vehicle outfitted with special sensors in a crash-worthiness test facility. In this test, the vehicle and all its contents travel at a velocity of 65 km/h, east, before the vehicle crashes into a barrier.



a. When the vehicle crashes into the rigid barrier, it stops almost immediately. What does the law of inertia (Newton's first law) predict about the motion of the passenger in the fraction of a second after the car collides with the barrier?

b. Explain the importance of seat belts and air bags from the point of view of Newton's first law.

49. The following diagrams show a crash test dummy sitting in the passenger seat of a vehicle. In this test, the vehicle and the crash test dummy are initially at rest; then the vehicle is struck from behind to simulate a rear-end collision.



a. In Diagram 1, the head restraint is properly adjusted—the centre of the head restraint is level with the top of the ears. Use Newton's second law to describe the motion of the head and body if this seat is suddenly thrust forward.

b. In Diagram 2, the head restraint is improperly adjusted—it is too low. In this case, the head is free to move somewhat independently of the body, constrained only by its attachment through the neck. Use the law of inertia (Newton's first law) to describe how the head will tend to move even though the seat is accelerating the rest of the body.

c. Explain why the injury caused by the scenario described in Diagram 2 is usually called whiplash.

1.9 Summary

The net force is the vector sum of all the forces acting on an object. For a vehicle moving on a road, the net force is the sum of the forces provided by the engine to move it forward and the resistive forces (such as rolling resistance and air resistance) that oppose the motion of the vehicle. Collectively, these resistive forces can be referred to as the force of friction. Applying Newton's second law in these circumstances often requires a calculation to determine the net force.

A special case occurs when the forces on an object are balanced and the net force is, therefore, zero. Newton's second law explains this circumstance by stating that since the net force is zero, the acceleration must also be zero. Another approach is to use Newton's first law, which states that when there is no net force, an object in motion will maintain its velocity and an object at rest will remain at rest. Newton's first law is also called the law of inertia because inertia is the property of an object to resist changes in its state of motion.

1.9 Questions

Knowledge

1. Draw two diagrams of a car on a highway. One diagram will illustrate the car travelling at a constant velocity. The other diagram will illustrate the car accelerating. Add labelled arrows to each of the diagrams to illustrate the relative size of each of the following vector quantities:

- force of friction
- applied force
- net force

2. Which diagram in question 1 illustrates Newton's first law? Which illustrates Newton's second law? Explain.

Applying Concepts

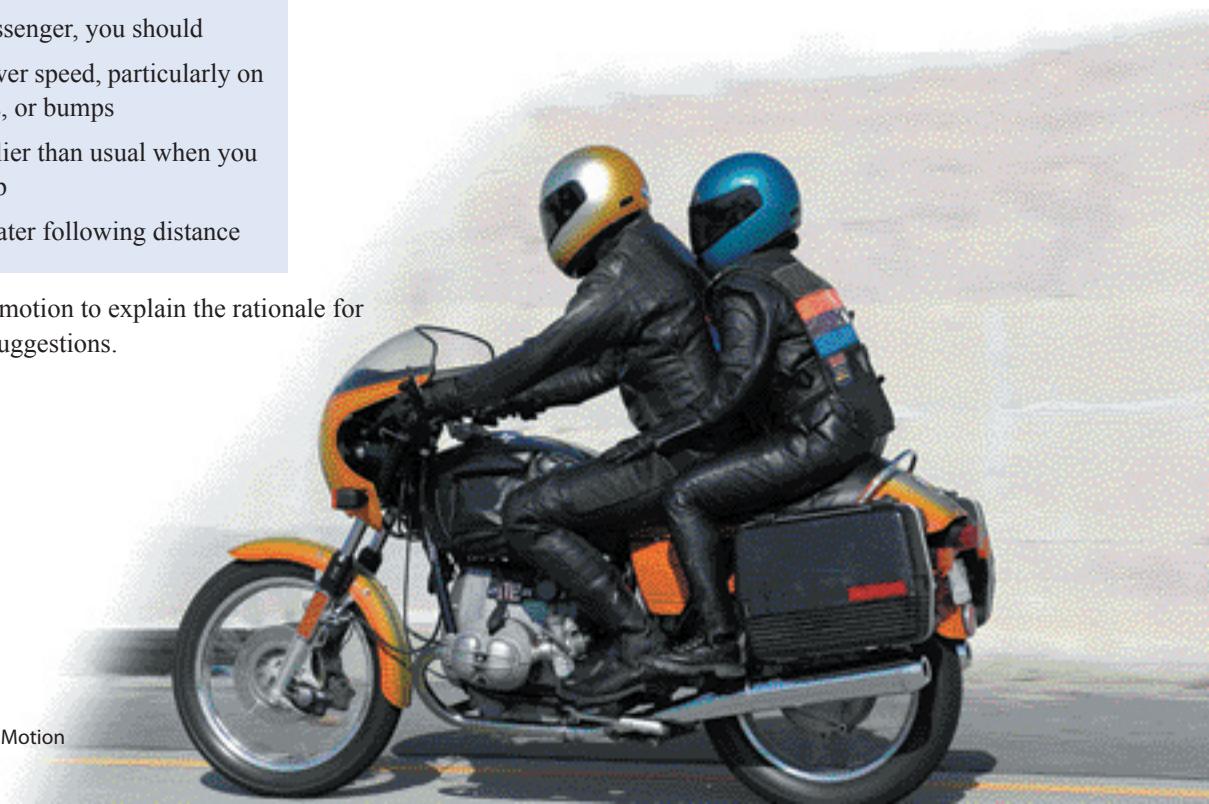
3. A motorcycle and its driver have a combined mass of 224 kg. The engine generates an applied force of 1200 N, south, while the frictional forces exert 375 N, north. Let south be considered the positive direction for this question.

a. Determine the acceleration of this motorcycle.
b. Determine the time for this motorcycle to accelerate from rest to 65.0 km/h, south.

4. The following excerpt was taken from an operator's handbook for motorcycles, mopeds, and power bikes. These are some of the suggestions given to drivers of these vehicles when carrying a passenger:

> When carrying a passenger, you should
>
> - operate at a lower speed, particularly on corners, curves, or bumps
> - slow down earlier than usual when you approach a stop
> - allow for a greater following distance

Use Newton's laws of motion to explain the rationale for each of these driving suggestions.



Chapter 1 Summary

In this chapter you applied the physics of uniform and accelerated motion to a variety of applications involving modes of transportation in Alberta. You saw how the position, displacement, and velocity vectors are very useful when planning a detailed trip using a map. You also saw that these ideas can be combined with acceleration and force vectors to develop a deeper understanding of the conditions that affect a vehicle's stopping distance.

In Chapter 2 you will continue this analysis by considering what happens when the stopping distance is inadequate and a collision does occur. The physics of collisions will build upon many of the concepts in this chapter and introduce you to some new ideas that spring from Newton's laws of motion.

Summarize Your Learning

In this chapter you learned a number of new terms, concepts, equations, and techniques for problem solving. You will have a much easier time recalling and applying the information you have learned if you take some time to organize it into some sort of pattern. Now that you have come to the end of this chapter, this is an appropriate time to focus on the patterns within the things you have learned.

Since the pattern has to be in a form that is meaningful to you, you have some options about how you can create this summary. Each of the following options is described on pages 552 and 553.

Option 1: Draw a concept map or a web diagram.	Option 2: Create a point-form summary.	Option 3: Write a story using key terms and concepts.	Option 4: Create a colourful poster.	Option 5: Build a model.	Option 6: Write a script for a skit (a mock news report).

Chapter 1 Review Questions

Knowledge

1. Define *uniform motion*.

2. List four quantities that are scalars.

3. List four quantities that are vectors.

4. Distinguish between scalar and vector quantities.

5. Demonstrate the proper use of conversion factors by finding the missing values.

a. 5.4 h = _____ s
b. 900 s = _____ h
c. 1500 m = _____ km
d. 4.75 km = _____ m
e. 35.5 m/s = _____ km/h
f. 85 km/h = _____ m/s

6. Define the term *velocity* in the following ways.

a. using a sentence
b. referring to a position–time graph
c. stating an equation

7. Define the term *acceleration* in the following ways.
   - **a.** using a sentence
   - **b.** referring to a velocity–time graph
   - **c.** stating an equation
8. Distinguish between the following terms: *reaction distance*, *braking distance*, and *stopping distance*.
9. Distinguish between the following terms: *applied force*, *force of friction*, and *net force*.
10. State Newton's first law of motion, and give an example of how it is used.
11. State Newton's second law of motion, and give an example of how it is used.

Applying Concepts

A great place for Canadians to visit is the nation's capital. Ottawa is a beautiful city with outstanding museums and other attractions that are surrounded by fabulous parks and gardens. Suppose you just arrived in Ottawa and you are planning the next few days of activities using this map.

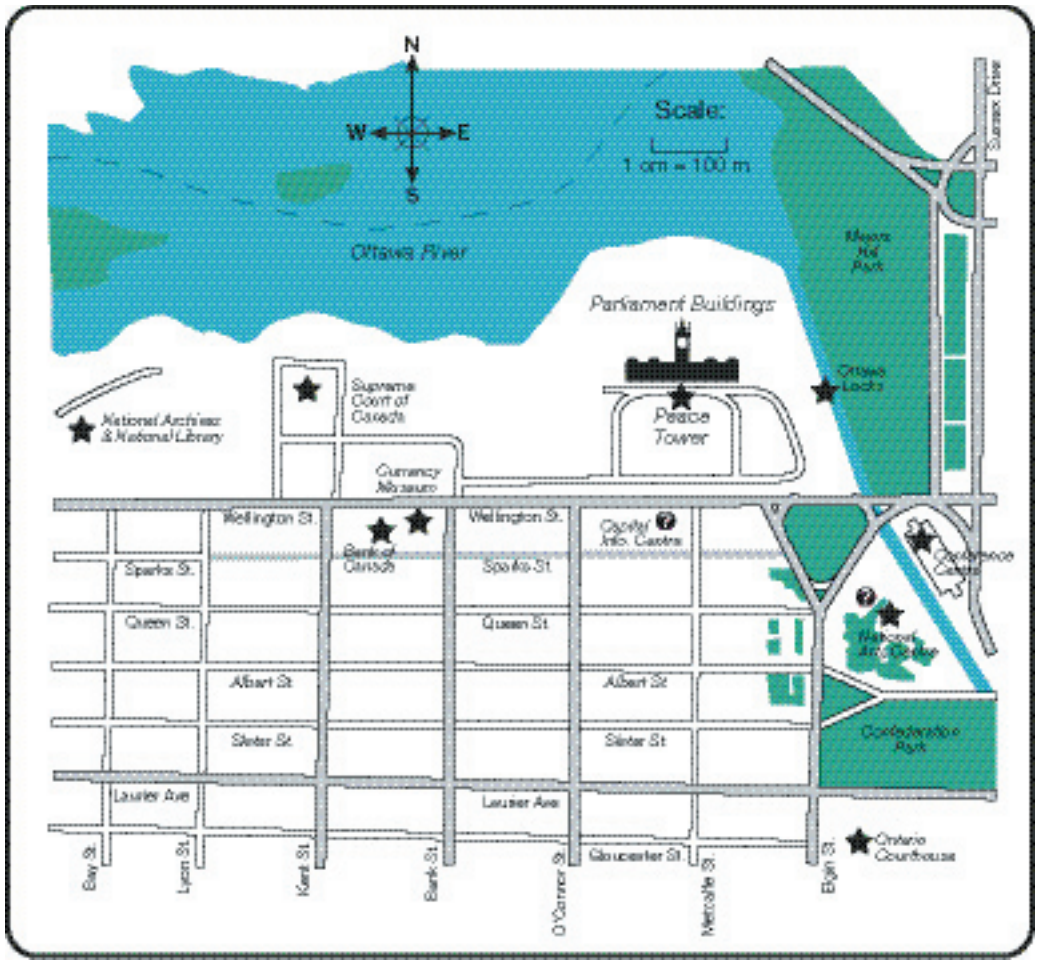


Figure B1.54: The National Arts Centre and the Ottawa Locks are only two of many fascinating sights to see in Ottawa.

Use a ruler and the map of Ottawa to answer questions 12 to 15. This map is available as a handout, called "Map of Ottawa," on the Science 20 Textbook CD. In terms of a sign convention, when dealing with things moving east-west, consider the positive direction to be east. North can be considered the positive direction for north-south motions.

12. Measure the missing displacements in the table with a ruler, and calculate the average velocity. Note that each solution should be done by listing the data, converting the units, choosing the equation, substituting the data, and then solving for the velocity.

Starting Point	Ending Point	Measured Displacement (m)	Time to Reach Ending Point (min)	Calculated Average Velocity (km/h)
corner of Metcalf St. and Gloucester St.	Peace Tower		9.0	
corner of Bay St. and Queen St.	National Arts Centre		22.0	
Ottawa Locks	corner of Laurier Ave. and Elgin St.		11.0	
Conference Centre	corner of Lyon St. and Sparks St.		19.0	
Supreme Court of Canada	corner of Kent St. and Gloucester St.		12.0	

13. Calculate the missing displacement, and determine the ending point by measuring with a ruler.

Starting Point	Average Velocity (km/h)	Time to Reach Ending Point (min)	Calculated Displacement (m)	Ending Point
corner of Metcalf St. and Wellington St.	3.2 km/h [W]	7.0		
Supreme Court of Canada	3.9 km/h [E]	10.5		
corner of Kent St. and Slater St.	5.3 km/h [N]	5.0		
National Arts Centre	4.4 km/h [W]	8.0		
Peace Tower	4.3 km/h [S]	2.5		

14. Imagine you just left a bus at the corner of Bay St. and Wellington St. You are standing at this corner, trying to find your location on the map.

a. Another tourist sees you with the map and asks how to get to the Capital Information Centre. Determine the distance and the position of this centre from your corner. Explain which value is the best answer to the tourist's question.

b. One way to show the tourist how to go from the corner of Bay and Wellington to the Capital Information Centre is to take him or her there yourself. If this walk takes 12.0 min, determine your velocity in kilometres per hour.

c. Having dropped off the tourist at the Capital Information Centre, you decide to walk to the Currency Museum, which takes an additional 5.0 min. Use a scale diagram and the head-to-tail method to determine the resultant displacement from the corner of Bay and Wellington to the Currency Museum.

d. Determine your average speed and average velocity, both in kilometres per hour, for the total journey from the corner of Bay and Wellington to the Capital Information Centre to the Currency Museum. Explain why these values are so different even though they describe the same trip.

15. Eventually, you end up at the Peace Tower in front of the Parliament buildings. You try to find your location on the map.

a. Determine the displacement of the Supreme Court of Canada from your location.

b. If you were able to walk with an average velocity of 3.0 km/h, west, along footpaths from the Peace Tower to the Supreme Court of Canada, determine the number of minutes this should take.

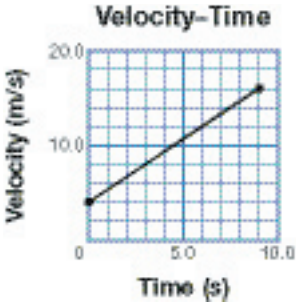
c. You walk with an average velocity of 3.6 km/h, south, from the Peace Tower for 8.0 min. Determine your final displacement and the point of your location on the map.

16. You have seen in this chapter that a graph can tell a story about the corresponding motion it describes. By carefully inspecting a velocity–time graph, you should be able to determine the

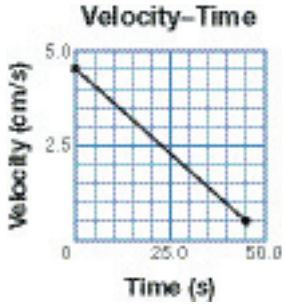
- time interval for the motion
- initial and final velocities
- acceleration during the time interval
- displacement during the time interval

Complete the process described for each of the following graphs. In each case, clearly communicate your answers.

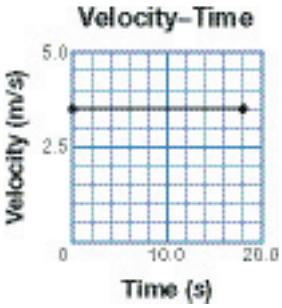
a.



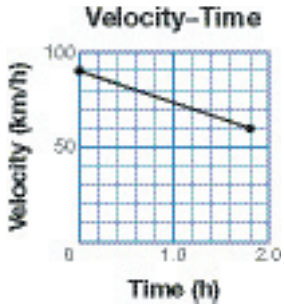
b.



c.



d.



Use the following information to answer questions 17 to 20.

The following diagram illustrates a car completing an emergency braking manoeuvre on a highway. Copy this diagram into your notebook. Leave enough room to add labels.

17. When the driver first noticed the need to stop, the vehicle was travelling 96.0 km/h, west. Add labels to your diagram for the locations of the car when the velocity was 96.0 km/h, west.

18. Consider the part of the diagram labelled "reaction distance."

a. Describe the motion of the car in this section. Support your answer by referring to Newton's laws of motion.

b. If the driver was drowsy, the reaction time might be 2.0 s. Use this value to calculate the reaction distance.

19. Consider the part of the diagram labelled "braking distance."

a. Describe the motion of the car in this section. Support your answer by referring to Newton's laws of motion.

b. The surface of the road was wet. In these circumstances, the deceleration available was only about 3.45 m/s^2. Use this value to calculate the braking time and the braking distance.

20. Consider the part of the diagram labelled "stopping distance."

a. Determine the stopping distance.

b. Conventional halogen headlights illuminate about 60 m of the road in front of a vehicle. High-intensity discharge (HID) headlights illuminate up to 100 m of the road. If this incident happened at night, could the driver have seen the hazard and had enough stopping distance to avoid a collision using either headlights?

c. If the posted speed limit was 100 km/h, why is it likely that the driver travelling at night under the conditions described in this question could be described in a police accident report as "driving at a speed unsafe for prevailing conditions"?